Evaluation of the *a*-Beta Instrument and the Distance Visibility Algorithm for Camera and Diver Visibility

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LONG-TERM GOALS

The Navy has a need to have instrumentation and algorithms that provide the warfighter with estimates of diver visibility and light attenuation for system performance. The long-term goal of this research effort is to provide the Navy with instrumentation and algorithms that have been scientifically and technically validated and are fundamentally sound. The algorithms are for diver and camera visibility as well as evaluating instrumentation that may be utilized and equipped aboard US Navy survey vessels.

OBJECTIVES

The Distance Visibility Algorithm (DiVA) has been put forth together with the a-Beta instrument (Hydro-optics, Biology, and Instrumentation Laboratories, HOBI Labs) as an improved method to provide the warfighter with diver and camera visibility as well as inherent optical properties that can be used by other electro-optical instrumentation. This effort is to evaluate whether the DiVA model and the a-Beta instrumentation significantly improve the visibility algorithms currently in use at NAVOCEANO. In addition, the a-Beta will be evaluated for its utility in providing optical properties in a variety of environments from clear ocean conditions to turbid resuspension-dominated regimes.

APPROACH

Both theoretical and empirical (in-situ measurement) techniques are used to evaluate the a-Beta and the DiVA algorithm. The theoretical approach is to compare the DiVA derivation provided by HOBI Labs with the work of previous investigators in visibility (e.g. Duntley and Preisendorfer, Mertens, and Dolin and Levin). The theoretical task is to evaluate the parameters within DiVA that are primary parameters in the “path radiance factor”, the “path attenuation coefficient”, and whether the expression of DiVA using the Modulation Transfer Function adds information. This will include determining the assumptions that are embedded within the DiVA model and determining the extent to which such assumptions can be made under normal littoral applications.

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The DiVA approach requires the target radiance attenuation and the path radiance attenuation, which in DiVA are assumed equal and represented by the a-Beta's attenuation measurement. The model assumes that the path radiance factor $\tilde{L}$ can be empirically determined. This factor is the integrated path radiance from the observer to the target, divided by (L_{T0} + L_{B0}), the target and background radiances. The DiVA also assumes a diffuse light field, a known contrast threshold, and target reflectivity. As reported by Maffione, the image contrast as a function of distance is given:

$$C(R) = Co\left\{1 + 2\tilde{L}\left[\frac{\exp(K_L R) - 1}{K_L}\right]\right\}^{-1}$$

and the visibility range is given by:

$$R = \frac{\ln\left[K_L / 2\tilde{L}(C_0 / C - 1) + 1\right]}{K_L},$$

where K_L is the path radiance attenuation coefficient measured by the a-Beta. The inherent contrast of the image is described by C_0 , which is the contrast at a range of zero while C is the contrast threshold ranging from 2 to 5% for most underwater applications.

An attempt to compare the DiVA approach to the Contrast Transmittance Theory (CTT) has been completed by Zaneveld and Pegau (personal communication). Their results are being scrutinized to determine how the DiVA and classical CTT approaches compare. The theoretical approach will also include a secondary Modulation Transfer Function approach that does not employ a simple four quadrant black and white disk as is used in the visibility work with the a-Beta and DiVA. Using underwater imaging of a series of equally spaced black and white lines of known spatial frequencies, this MTF approach (NRL/PSI) can be used to evaluate the range dependence of the path radiance.

The final portion of the evaluation will be a comparison of the a-Beta measurements with other commonly measured optical properties (absorption and attenuation meters, scattering sensors, and radiometers). The purpose of this is to evaluate the limits of performance of the a-Beta and to determine our ability to use the a-Beta to retrieve optical parameters critical to the performance of electro-optical systems. The comparison with other measurements will determine the sensitivity of the a-Beta to system parameters and indicate where Monte Carlo simulations are required to determine the relationship between the path radiance factor $\tilde{L}$ and other optical factors. This will also show whether or not the DiVA model appropriately incorporates the "measured property with the a-Beta" to the "required parameter" in the visibility computations (e.g. is K_L correct for the visibility calculation)..

WORK COMPLETED

An attempt has been made to evaluate the key parameters within the DiVA model, how these relate to previous work, and whether K_L, the attenuation coefficient measured by the a-Beta, is appropriate for either/both the target and path radiance attenuation coefficients. The theoretical soundness of the DiVA formulation has been investigated at length with several issues that have arisen regarding the path radiance function and its validity. This work has been lead by Dr. McBride who is comparing the theoretical framework of DiVA with that described by Mertens (1970) and Duntley (1963). The theoretical treatment has been focused around the "radiance attenuation coefficient, K_L" and the "radiance path function, L^*" (this is the radiance integrated over all angles at a point along a line between the observer and the target). DiVA assumes an attenuation of K_L from all points between the observer and the target. The method by which HOBI Labs obtains the path radiance factor using the black and white Secchi disk and "background radiance" is being reviewed for its proper use in defining the background radiance and the influence that this will have on the path radiance factor. A different set of spatial frequency targets have been designed for comparison with the DiVA approach.

In-situ data has been collected serendipitously during a recent National Ocean Partnership Program exercise. Under ONR funding of the Ocean Coastal Response Analysis System project there is a diver visibility task for NRL, Planning Systems Inc., and CNMOC as an extension of Gauging Littoral Optics for the Warfighter (GLOW) in which targets with known spatial frequencies were photographed at discrete ranges. These are being used to evaluate the MTF of the environment and to compare this with the DiVA formulation (Figure one).

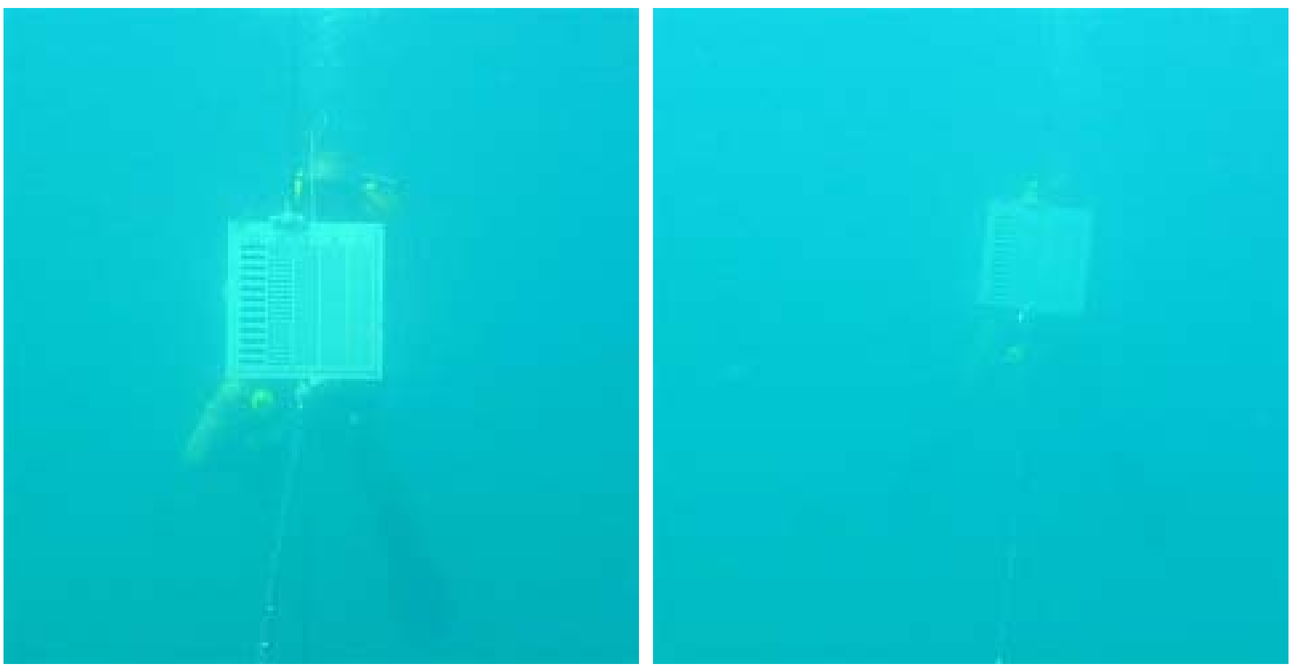

Figure 1: Contrast Panels at 20 feet (left) and 30 feet (right) distances
[Contrast panels of 32, 16, 8, 4, and 2 mm separation at distances of 20 and 30 feet in water off of Pensacola Beach, FL; diver visibility was reported to be 65 feet]

RESULTS

The DiVA algorithm attempts to parameterize, in an optically homogeneous water column, both the path radiance and the target radiance as functions of the same "radiance attenuation coefficient" K_L measured by the HOBI Labs' a-Beta instrument. In a personal communication, Zaneveld and Pegau compared the DiVA approach and the Contrast Transmittance Theory (CTT) derived from the work of

Preisendorfer, Duntley, Tyler and Petzold. They make the case, starting from the radiative transfer equation, that K_L must equal to c, the total attenuation coefficient and that the a-Beta does not measure c. Aside from a typo in one equation, where the $L^* /(c - K_L)$ term should not be present, their derivation can be found in textbooks and is an accepted approach to underwater visibility. There are questions about the derivation to the Michelsen contrast that remain.

A key issue that has been investigated is why and how DiVA can use the same attenuation coefficient K_L for both target and path radiance. Fundamentally it is unclear why these should be equivalent. We have identified three areas to help resolve this issue. The largest difference noted between the Zaneveld and Pegau evaluation and the DiVA model is in the treatment of path radiance attenuation and the comments from Zaneveld and Pegau that indicated little "information added" in the DiVA formulation. The preliminary conclusion about DiVA is that it represents contrast between large areas of an object without contributions from the light field surrounding the target.

1. How does the target radiance diminish as distance between the observer and target increases?
CTT does not account for the replenishing effect of forward scattered light and cannot therefore accurately predict how the size of the target affects the propagation of its radiance as a function of distance. We expect a functional form $L_T(R) = L_T(0)\exp(-Tr)$, where T is the attenuation coefficient for the target radiance. CTT assumes that $T=c$ no matter what the size of the target while DiVA assumes that $T= K_L$. We expect that the radiance of larger targets should fall off more slowly with distance than the radiance of smaller targets. This is because the radiance from neighboring points on the target will be scattered into each other's line of sight with respect to the observer and will therefore replenish light scattered out of each line of sight. The target attenuation coefficient T should therefore vary between c for small targets and the diffuse attenuation coefficient K for large targets. Other Modulation Transfer Function approaches take into account the influence of target size on the target radiance attenuation. How DiVA compares with this requires further evaluation (Walker, 1994).

2. How does the path radiance increase as distance between the observer and target increases
For horizontal viewing, we expect a functional form $L_P(R) = L_B(\infty)(1\text{-}\exp(-Pr))$, where P is an attenuation coefficient to be determined by experiment and $L_B(\infty)$ is the total path radiance along the horizontal line of sight. For horizontal viewing, CTT theory predicts that $P=c$ while DiVA assumes that $P= K_L$. Data from the NOPP experiment and HOBI Labs data will be used to evaluate the K_L assumption in DiVA.

3. How does HOBI Labs' K_L compare to *a*, *c*, *K* and experimentally derived *P* and *T*?
Data collected this year with HOBI Labs using black/white quadrant targets and the PSI bar targets are being used to determine the relationships between a, c, K and K_L and whether K_L can be used for both target and path radiance attenuation coefficients. This includes calculating T and P using experimental data and then comparing these with the a-Beta's K_L and Wetlabs absorption and attenuation coefficients, a and c.

IMPACT/APPLICATIONS

The DiVA formulation, if shown to be robust and valid, can offer the warfighter a new measure of diver and camera visibility. The use of the a-Beta, and the validation of K_L , is critical for the use of the DiVA model. The BattleSpace Profiler (BSP) is considering the a-Beta for integration to yield diver visibility from in-situ measurements. This program will determine whether this effort is more advantageous than the current Navy's algorithm for visibility.

TRANSITIONS

The N096 electro-optical roadmap has indicated that diver visibility is a high priority for MCM and NSW operations. Therefore N75 has endorsed the effort to put optical instrumentation on the BattleSpace Profiler that gives the warfighter a quick indication of visibility and camera ranges. The transition of DiVA and the a-Beta instrumentation depend on the validation and evaluation of the technology and algorithm being investigated in this program.

RELATED PROJECTS

National Ocean Partnership Program is sponsoring the Ocean Response Coastal Analysis System (ORCAS) in which current Navy visibility algorithms are being modified.

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